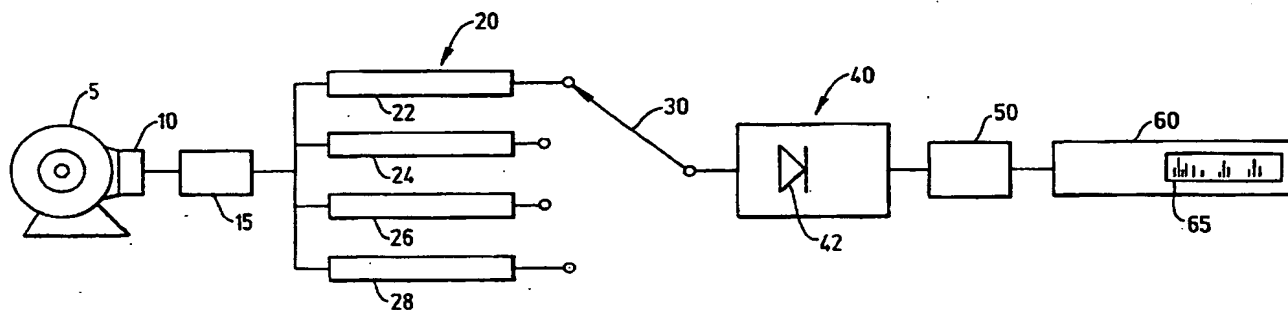




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(54) Title: ENVELOPE ENHANCEMENT SYSTEM FOR DETECTING ANOMALOUS VIBRATION MEASUREMENTS



(57) Abstract

A vibration detecting and condition monitoring system for the press section, including felts, rollers and presses, employing a feature extracting circuit having a selectable plurality of Bessel type bandpass filters (20) and an enveloping circuit (40) to square the bandpassed signal output prior to FFT analysis (60) of the signal. The system enables the enhancement and detection of highly impulsive signals in the frequency domain, that are indicative of defects in machinery operation.

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Envelope enhancement system for detecting
anomalous vibration measurements

Background of the Invention

5 This invention relates to a quality control and fault
monitoring system for use in paper machine press sections,
including felts, rolls and presses.

10 In the prior art, techniques to detect vibrations have
been found to be lacking in some important areas. One such
area is the detection of defects occurring over a short
period of time (e.g., an impulsive defect). The present
invention allows for the rapid and efficient detection of
such impulsive defects.

15 By way of example, some prior devices detect anomalous
vibrations in machinery by employing a technique known as
synchronous time averaging, as explained in the 1965
technical paper by Charles R. Trimble, "What is Special
Averaging", Hewlett-Packard Technical Paper 1965. Briefly,
and in general terms, in synchronous averaging a point on a
rotating piece of machinery, such as a power shaft, is marked
20 with a trigger, such as a reflective tape or a grease spot on
the shaft, and a photo-tachometer is used to monitor the
actual displacement of the rotating machinery, be it angular
displacement or linear displacement. Keyphasers, velocity
transducers or accelerometers may also be employed in this
25 task. A series of measurements of the rotating machinery is
taken over time, averaged and analyzed by an analyzer, which
is often a digital computer. The trigger is used as a
reference point in time in the analysis. The analyzer
collects data over one periodic cycle of the machinery, and
30 repeats the data collection over a series of such periodic
cycles. In the event a synchronous defect is present, such
as a flat spot in a roll or a felt related anomaly, the
defect will appear at the same point in time from the
trigger. Non-synchronous defects or events occur randomly
35 with respect to the triggering pulse. The idea behind
synchronous averaging is that by repeated measurements with
an analyzer, a defect will manifest itself over time as a
irregularity in the data collected by the analyzer.

While synchronous time averaging appears to be an ideal system for detecting defects in theory, in practice several factors are responsible for mitigating its effectiveness. For one thing, synchronous averaging appears to be better suited to detecting low frequency defect signals, such as stationary sinusoidal vibrations due to imbalance and misalignment of shafts. Typically these vibration signals are very low frequency signals. Because the sensitivity limits of transducers can be reached at these very low frequencies, for synchronous detection to work best a very long time interval for sampling the machinery is often required. Also, if data from synchronous defect detection is in the time domain rather than in the frequency domain, it is sometimes difficult to detect highly impulsive defects, such as those vibrations induced by a roll or press anomaly or a felt problem, which may not and often do not coincide with the longer periodic vibrations present in a rotating machinery. These impulsive defects often produce impulse signals containing high frequency sinusoidals, rather than only lower frequency sinusoids of stationary vibration defect signals. The repetitive frequencies of these phenomena (the beat) can be very low.

Finally, if no signal enhancement of impulse signals having high frequency components is performed, such as by enveloping, there is a significant risk that a transducer signal will be masked by background structural machine noise, which is always present and can be present over all frequencies. Although a defective felt press roll or bearing can transmit a significant force through the bearing housing, the response of the supporting structure is usually very small (as measured by an accelerometer mounted near the bearing load zone), and, as a consequence, the detection of the defect runs the risk of being masked by noise, especially if measured in the frequency domain.

In rotating machinery enveloping is most significant on repetitive roller defects of the impact type, especially low-force impacts, and less important on vibrations due to non-impact defects, such as misalignment.

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Synchronous time averaging for very slow speeds has the further disadvantage that due to the long sampling time required for measurement, the speed variations in the machinery being measured, such as are common in paper machines, will adversely influence the result of the averaging process. As the enveloping techniques of the present invention have inherent real time averaging capabilities present in it, consequently the sampling time does not have to be as long due to the enveloping process, as explained more fully below.

Summary of the Invention

The present invention is directed to providing for the detection of defects in vibrating or rotating machinery, including but not limited to vibrations caused by misalignments, broken parts, pitted or flat spots in rollers and loose tolerances, to enhance the quality control of the machinery, as well as to predict the possible failure of the machinery.

The present invention employs a novel configuration of hardware not previously found in paper machines in the past. The present invention has been designed for use with paper machine press monitoring, with the intention of indicating whether the felts that handle the paper are anomalous, which damage the paper flow and the quality of the paper product. The present invention has also been used to monitor press rolls. The present invention also has more general applications, to include all types of condition monitoring on rotating and vibrating machinery. For example, another application of equivalent nature can be found in the quality control of roller mills in steel plants.

The present invention is capable of detecting anomalous vibrations that may be highly impulsive and contain high frequency sinusoidal components.

The present invention is capable of detecting anomalous vibrations in a short period of time, without requiring the storing and analyzing of extensive data over a long sampling history. Hence, the present invention may be suitable for

real time analysis.

The present invention is capable of the enhancement of small signals sensed by a transducer, such as an accelerometer, as well as the mapping of such a signal from the time domain to the frequency domain, to better overcome the tendency of such signals to be lost in noise.

The present invention achieves this result by employing a novel configuration that samples vibration signals with an accelerometer, employs selectable band pass filters to filter these signals, uses small signal enhancement techniques such as envelope detection to further shape and enhance these signals, and maps these vibration signals to the frequency domain using Fast Fourier Transform (FFT) spectrum analysis. In lieu of the frequency domain the averaged signals could be displayed in the time domain.

Other features and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

Brief Description of the Drawing

FIG. 1 is a circuit block diagram of the present invention.

Description of the Preferred Embodiment

The present invention employs three stages for condition monitoring of a machine: a sensing stage comprising transducer 10 and signal conditioning circuit 15, a feature extracting stage comprising band pass filters 20, enveloping detector circuit 40, and low pass filter 50, and a final analysis stage comprising Fast Fourier Transform (FFT) spectral analyzer 60.

Fig. 1 shows a circuit block diagram of the present invention. A vibration detecting transducer 10, such as an accelerometer, picks up vibration signals from machinery 5 and transmits these signals to a selectable band pass filter 20. The transducer is connected to the machine in the manner

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known in the art to produce optimal pickup of signals, such as, for example, mounting the transducer so that no air gaps are interspaced between it and the machine, sufficient contact is generated with the machine, and the proper sensor sensitivity for optimal signal-to-noise ratio is achieved, which is in the range of 10 to 500 mv/G, and generally centered around 50-100 mv/G, based on the application.

After the transducer output, a signal conditioner 15 may be employed to scale the output of the transducer so that it lies within the voltage range required for compatibility with the rest of the circuits in the system.

Band pass filter 20 is set to reject relatively low frequency signals and pass relatively higher frequency signals, and is selectable in the range of signal frequencies it may pass by a switch 30. As is known per se in the art, band pass filters attenuate frequencies outside the passband. The frequency range may be user selectable according to the criteria of the speed range of the machinery being analyzed and/or the analyzing range of the system. The filter criteria selection is based on suitable rejection of the low frequency sinusoids while optimizing the passband of the defect harmonics. In the preferred embodiment four such band pass filters are employed, filters 22, 24, 26 and 28, having pass band frequencies of 0.5-10 Hz, 5-100 Hz, 50-1,000 Hz, and 500-10,000 Hz.

The particular filter selected by the user may be selected according to the frequency band desired, the speed range of the machinery, or the analyzing range, as shown in the following table. The frequency band is the frequency of the signal in the time domain, the speed range is the speed of a rotating machinery sampled and the analyzing range is the frequency of the spectral analyzer used to display the output.

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	<u>FREQUENCY BAND</u>	<u>SPEED RANGE</u>	<u>ANALYZING RANGE</u>
	0.5 - 10 Hz	0-5 RPM	0-1 Hz
	5-100 Hz	0-50 RPM	0-10 Hz
	50-1,000 Hz	25-500 RPM	0-100 Hz
5	500-10,000 Hz	250-5,000 RPM	0-1,000 Hz

The user selectable bandpass filter may also be set to any empirically determined frequency band that has been found to optimize the transducer signal-to-noise ratio, and to match structural or transducer resonance.

10 In the preferred embodiment band pass filter 20 is of the Bessel type, in order to minimize phase distortion of the signal.

After a vibration signal passes through selectable band pass filter 20, it is conditioned by envelope detector 40. 15 Envelope detector 40 enhances high frequency components of impulsive signals, such as of the kind often produced by defects in machinery, by employing signal enhancement techniques such as enveloping the band passed signal with a circuit that approximately squares the signal. Signal 20 enhancement is important when mapping a highly impulsive signal into the frequency domain, to help augment the signal and distinguish it from noise.

More particularly, the present invention employs envelope detector 40 to detect and amplify high frequency 25 signals. This is achieved with a circuit that approximately squares the signal. In the simplest embodiment, this can be done by a peak detector or rectifier using a diode 42. Other known techniques for squaring the band passed signal may be employed.

30 In this way the high frequency harmonic amplitudes, of the kind most likely to be found in an impulsive signal, are enhanced and made to better stand out from normal vibration signals. In a sense the feature extracting stage of the present invention widens out the sensed signals and performs 35 a kind of instantaneous averaging, eliminating the necessity of long sampling times as might occur under synchronous time averaging.

To illustrate the importance of the feature extracting

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stage of the present invention, consider the case where a periodic defect signals is present, that can be represented in a Fourier Series as:

$$f(x) = 1/2 A_0 + \sum [A_n \cos(n\omega_0 x) + B_n \sin(n\omega_0 x)]$$

5 where $\omega = 2\pi/T$, T = the period of the defect, and

$$A_n = (2/T) \int f(x) \cos(n\omega_0 x) dx$$

and

$$B_n = (2/T) \int f(x) \sin(n\omega_0 x) dx$$

for $n = 0, 1, 2, \dots$

10 and the coefficients A_n and B_n are the Fourier Coefficients, with the integrals taken over the period of the function.

Thus, as is well known per se, any periodic function can be formed out of a sum of sine and cosine functions that contain integral n multiples of the periodic function frequency (e.g., harmonics).

If the function is squared, e.g. $f(x) * f(x)$, when the Fourier Series is expanded there become apparent terms such as $(\sin a)(\sin B)$ which can be reduced to a series of sums and differences using the trigonometric equation: $(\sin$
20 $a)(\sin B) = 1/2 \cos(a - B) - 1/2 \cos(a + B)$.

Hence if a function $f(x)$, representing a transducer output, is filtered to pass only the higher orders of frequencies (which would more likely be the defect indicating frequencies), say, by way of example, frequencies greater
25 than the 50th harmonic, and if this filtered function is squared, we would obtain:

$$\begin{aligned} f(x) * f(x) &= [\sin(51x) + \sin(52x) + \dots \sin(100x)]^2 \\ &= \sin(51x)\sin(51x) + 2\sin(51x)\sin(52x) + \dots \\ &\quad + 2\sin(51x)\sin(100x) + 2\sin(52x)\sin(100x) \end{aligned}$$

30 Using the above trigonometric equation, the components such as $\sin(51x)\sin(52x)$ can be broken down into sum and difference components $(a \pm B)$, such as, by way of example, 52-51 and 52+51, to give:
1/2cos(1x) - 1/2 cos(103x), etc.

35 In the present invention only the difference components, such as 1x in the above example, rather than the sum components, such as 103x, would be saved, as only these

difference component signals would be within the analysis measurement range of interest. The higher frequency sum component signals could be filtered out from the desired difference component signals with a low pass filter 50 prior to analysis by spectrum analyzer 60.

Thus, according to the above example, the bandpassed signals from transducer 10, after passing through envelope detector 40 but prior to the signals passing through low pass filter 50, would contain difference component harmonics such as the vectorial sum of harmonics comprising the (52nd-51st) + (53rd - 52nd) + (54th - 53rd) + ... (100th - 99th) harmonics, that, as these components are summed, would appear as a large 1x difference component signal that can be normally processed by the Fast Fourier Transform (FFT) conversion analyzer 60. In general, for all the harmonic components spaced by spaced by n harmonics apart, a series of n*x difference component signals from any defect vibration would be produced, with each these components, 1X, 2X, 3X, . . . etc. appearing on a Fast Fourier Transform (FFT) spectral amplitude analyzer as peaks spaced at 1X, 2X, 3X . . . etc. of the frequency of the defect.

Hence a vibrating signal having a frequency f_a in the time domain (which could be a normal vibration signal, or a defective vibration such as the result of a flat spot on a rotating roll), would appear in the amplitude spectrum plot over the frequency domain as phaser(s) located at a n*times the frequency f_a , as indicating in window 65 of analyzer 60.

Thus a defect indicating signal processed by the present invention produces such peaks that stand out in a more prominent manner in a spectral analyzer than would a similar signal not so processed.

In analyzer 60 the conditioned and band passed filtered vibration signals from the time domain are mapped to the frequency domain, preferably using the techniques of Fast Fourier Transform (FFT) analysis, as is known per se in the art of signal processing. In general, any type of signal transform may be employed. Indeed, even an analyzer in the time domain, such as an oscilloscope, may be employed.

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However, by utilizing the frequency domain of a signal rather than its time domain, and by augmenting and conditioning highly impulsive signals that are frequently characteristic of signals indicating defective vibrations, the robustness of a vibrating machinery can be more readily ascertained.

A processor may be employed as part of analyzer 60 to ascertain the nature of a vibration signal, such as whether it is normal or abnormal, or whether it is impulsive, sinusoidal, Gaussian, some combination thereof or representative of any other known signal. In this way the processor may be used to store data to make predictions about the likelihood of future failure of the machinery, based on the signals generated by the same machine or similar classes of machines in the past. Furthermore, the data generated by the present invention may be used to pinpoint likely sources of vibration, and to take appropriate remedies in the event the vibrations indicate defective modes of operation of the machinery. Thus the present invention may be used as not only a system for failure analysis in a machine but also as a system quality control of the machine.

Though the present invention employs in the preferred embodiment relatively simple implementations for enhancement of signals, one skilled in the art could implement more complex implementations using the teachings of the present invention, such as synchronous demodulation or digital demodulation. Examples of such signal enhancing techniques may be found in U.S. Patent No. 4,768,380, incorporated herein in its entirety.

It will be apparent from the foregoing that, while particular forms of the invention have been illustrated and described, various modifications can be made without departing from the spirit and scope of the invention. Accordingly, it is not intended that the invention be limited, except as by the appended claims.

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CLAIMS

1. In a paper machine felt press or the like, a vibration detection system comprising: a sensor to sense signals representative of vibrations from said press; a feature
5 extracting circuit having at least one band pass filter for receiving said signals and passing predetermined frequencies of said signals, and an enveloping circuit to substantially square said band passed signals; an analyzer for representing said band passed signals.
- 10 2. The vibration detection system according to claim 1, wherein said analyzer is a analyzer that represents said band passed signals in the frequency domain.
3. The vibration detection system according to claim 2,
15 wherein said enveloping circuit comprises a rectifier, and said analyzer is a FFT spectral analyzer.
4. The vibration detection system according to claim 2, wherein said band passed filter is a Bessel filter.
5. The vibration detection system according to claim 2,
20 wherein said feature extracting circuit has a plurality of said band passed filters, and said filters are operably selectable to receive said signals from said sensor.
6. The vibration detection system according to claim 5,
25 wherein said filters are operably selectable by a switch, and said plurality of filters equals at least four filters, said four filters passing signals in the range of between .5 Hz to 10 kHz.
7. The vibration detection system according to claim 1, wherein said analyzer is an oscilloscope that represents said band passed signals in the time domain.

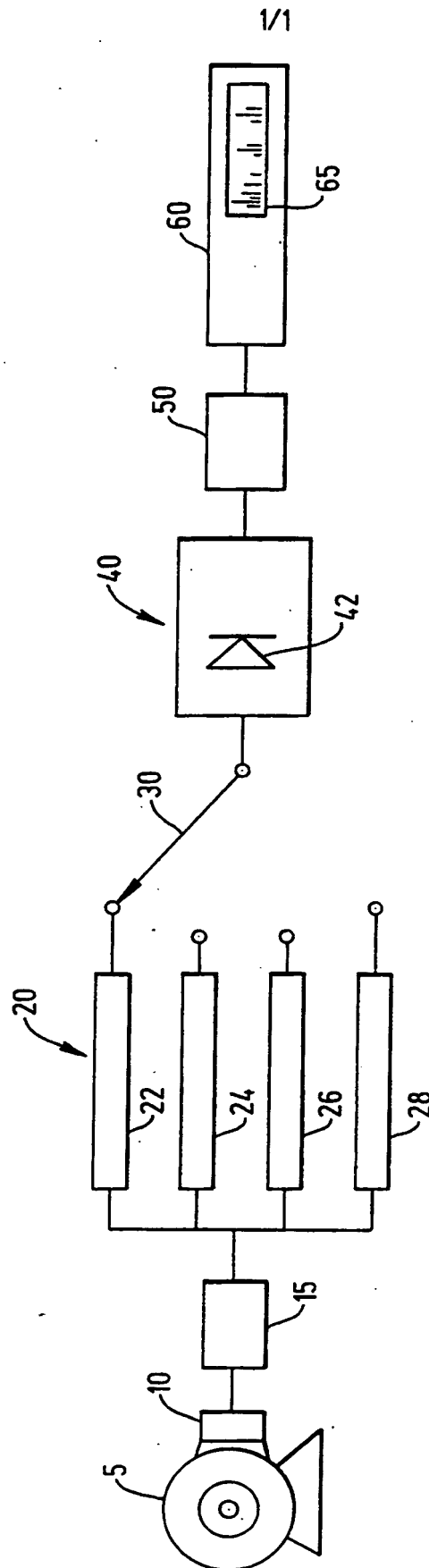


FIG. 1

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INTERNATIONAL SEARCH REPORT

Inter. Application No
PCT/US 93/11984A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G01H1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G01H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,3 641 550 (LYNAS ET AL) 8 February 1972 see figure 1 ---	1
A,P	PATENT ABSTRACTS OF JAPAN vol. 17, no. 357 (P-1568) 6 July 1993 & JP,A,05 052 644 (ONO SOKKI CO. LTD.) 2 March 1993 see abstract ---	1
A	US,A,4 768 380 (VERMEIREN ET AL) 6 September 1988 cited in the application -----	

☐ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

information on patent family members

Inter. .nal Application No

PCT/US 93/11984

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-3641550	08-02-72	CH-A- 512737 DE-A,B,C 2010226 FR-A- 2037684 GB-A- 1254219	15-09-71 10-09-70 31-12-70 17-11-71
US-A-4768380	06-09-88	NL-A- 8503294 EP-A,B 0227138 JP-B- 6017852 JP-A- 62132141	16-06-87 01-07-87 09-03-94 15-06-87

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